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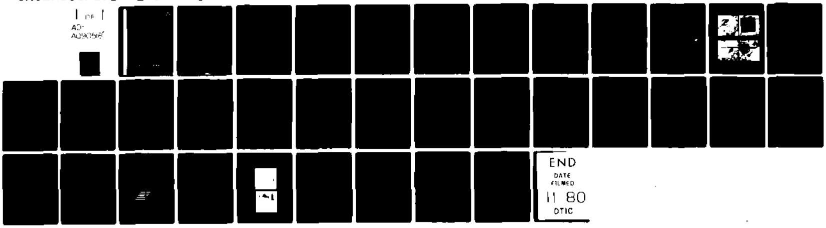

LEVEL II

138300-55-T

ARRAY I PHOTO IMAGERY ANALYSIS

AD A090518

M. LOPEZ
Radar and Optics Division

JULY 1980

U.S. Army Mobility Equipment
Research and Development Command
Ft. Belvoir, VA
Contract DAAK70-78-C-0198

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This report presents the results of the analysis and evaluation of aerial photography collected during test flights in July 1979 of a U.S. Navy RF-8G with a KS-87B framing camera over a test array of surface and buried mines, mine detection equipment, and other military equipment and elements. A standard photo search procedure was used in the initial examination of the photography, consisting of a monoscan followed by a stereo search. Each element in the test array was rated as being detectable, partially detectable, or

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20. Abstract (Continued)

non-detectable. Obscuration of mines by vegetation had an impact on detectability, as expected, but was not a major negating factor. Available ground resolution proved to be a severe limitation, because of the small size of the mines. The low contrast of the EKC 3411 film also limited detectability. It is recommended that an investigation be made to identify improved search techniques and that higher resolution and greater film contrast be employed in future tests.

PREFACE

The objective of the minefield detection project is to determine the effectiveness of remote sensing systems and other methods of detecting and identifying mines, minefields, minelaying equipment, or minelaying operations, and to recommend continuing effort on the most promising methods.

Work under the project concerned with each of the concepts to be investigated is being performed in a sequence of four major tasks: (1) identification and screening of promising techniques; (2) preliminary systems analysis and definition of experimental or other data acquisition systems; (3) acquisition of critical data through experiment, literature survey, or access to SCI; and (4) evaluation of conceptual systems for technical performance and military usefulness.

This is one of a series of reports documenting technical effort and results achieved during the project. This report covers work performed under Task 3, Critical Data Acquisition, for conducting analysis of aerial photographic coverage of a test array located on a site near Ann Arbor, MI.

Dr. J. Roland Gonano was the Contracting Officer's Technical Representative for the program, Mr. Henry McKenney was the Radar and Optics Division Program Manager, and Mr. Manuel Lopez supervised the data analysis.

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1
INTRODUCTION

In July and August 1979, a series of test flights were conducted over Test Array No. 1, an installation of surface and buried mines, mine detection equipment, and other military equipment and elements located near Ann Arbor, MI for use in testing and evaluating remote minefield detection techniques. This report presents the results of the analysis and evaluation of aerial photography collected during these test flights. The primary objective of this analysis was to test the capability of these sensors for remote minefield detection. A secondary objective was to examine the specific effects of vegetation obscuration of the mines, contrast between target and background, and ground resolution of the sensor on minefield detection capability.

The photo analysis was based on aerial photography collected by a U.S. Navy RF-8G with a KS-87B framing camera during the period 25 through 27 July 1979. A standard photo search procedure was used in the initial examination of the photography, consisting of a monoscan followed by a stereo search. Each element in the test array was rated as being detectable, partially detectable, or non-detectable. Obscuration of mines by vegetation had an impact on detectability, as expected, but was not a major negating factor. Available ground resolution proved to be a severe limitation, because of the small size of the mines. The low contrast of the EKC 3411 film also limited detectability. It is recommended that an investigation be made to identify improved search techniques and that higher resolution and greater film contrast be employed in future tests. Section 2 describes the major findings in this analysis. Section 3 presents results and conclusions based on these major findings.

2
TECHNICAL DISCUSSION

2.1 ARRAY AND ENVIRONMENTAL CONDITIONS

The minefield used at Ann Arbor is described in complete detail in the report entitled "Test Array No. 1 for Mine Detection Experiments," R. Maes, January 1980, No. 138300-38-T. A schematic layout of the array is shown in Figure 2-1. Photographs of the mines installed in the array are shown in Figure 2-2. The elements of the array that were examined in detail are (in order of priority):

Elements 1, 2, 3 - These three contained the surface mines. Element 1 contained the TM-46's (metal), Element 2 the PM-60's (plastic), and Element 3 the M-19 (plastic). The area in which these three elements were located was also called the new growth area because the vegetation was younger than that found in the other portions of the array.

Elements 5, 6 - The handburied mines, TM-46 and PM-60, respectively, were located in these two areas.

Elements 7, 8 - The furrows dug by the minelayer were situated here. Element 7 was a covered furrow while Element 8 was left uncovered during the collection.

Element 9 - The minecord (i.e., a string of mines) was buried in this area.

Element 10 - This section consisted only of dummy mine holes.

Elements 11, 15 - These two elements contained the calibration and instrumentation arrays.

Elements 12, 16 - These two sections contained the artillery scatterable mines and the simulated impace holes.

The vegetation, alfalfa plus mixed grasses, was approximately one ft high, on the average, throughout array Elements 1, 2 and 3.

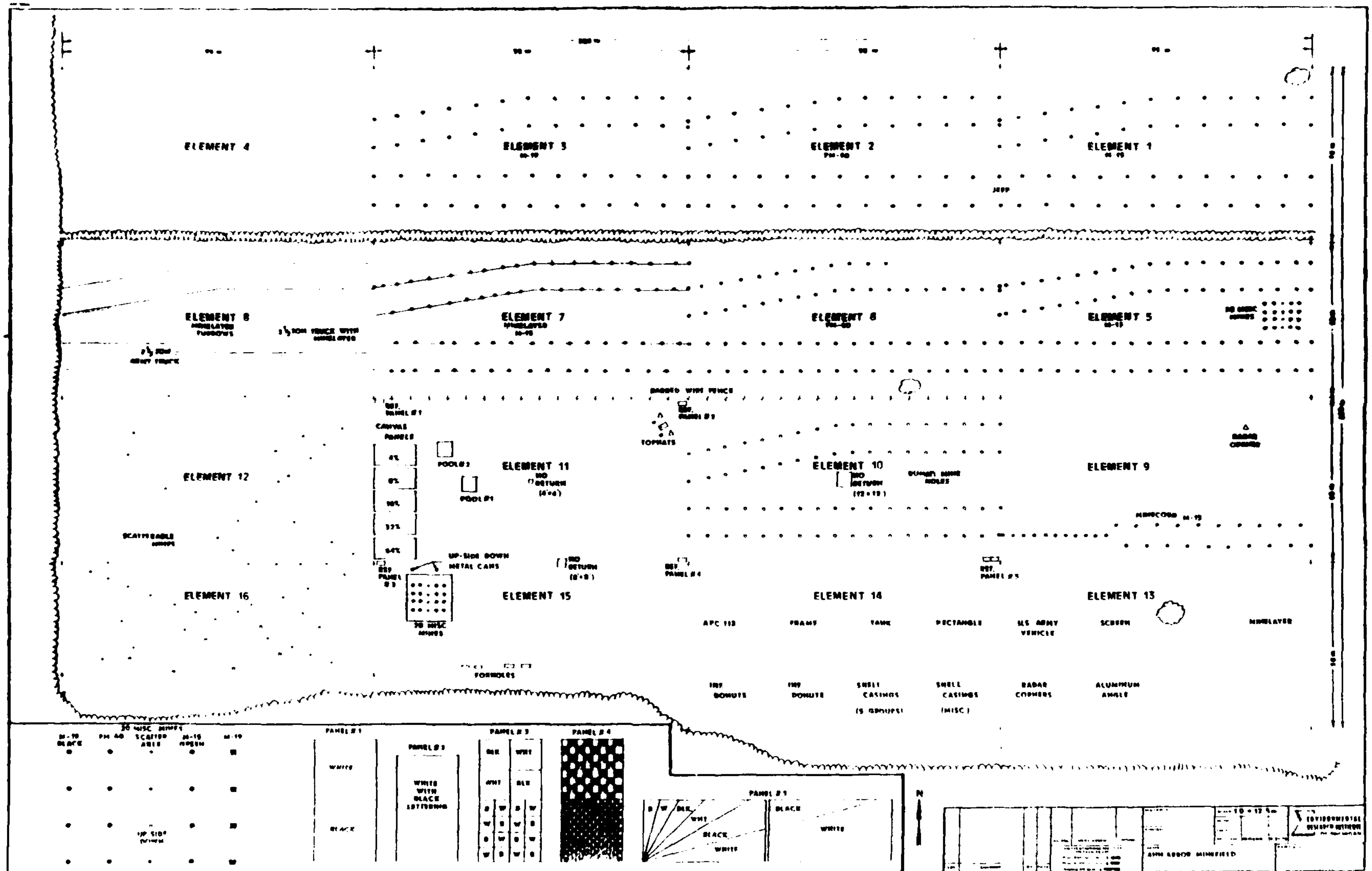
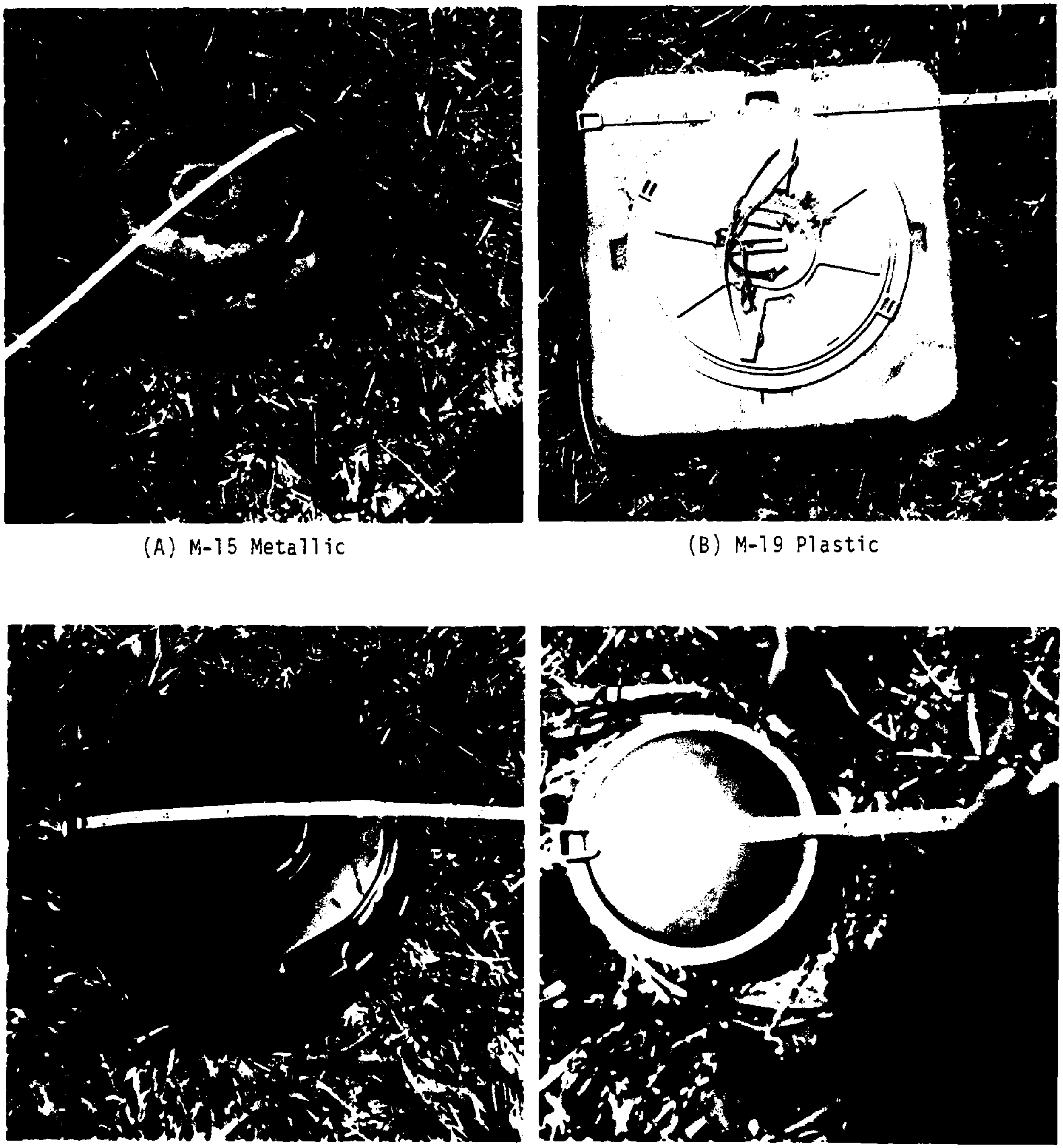


Figure 2-1. Test Array No. 1



(A) M-15 Metallic

(B) M-19 Plastic

(C) PM-60 Plastic

(D) Scatterable Mines-Metallic

Figure 2-2. Mines Used in Test Array

The vegetation in the remaining elements was approximately one ft high also, but appeared to be sparser than in the new growth area (Elements 1-3).

The soil was very moist on the day of collection, 27 July 1979, because of heavy rains two days prior. Approximately 2.5 in. fell in the 24 hours prior to collection. The moisture may have had an effect on the alfalfa leaf reflectance at the time of collection.

Weather conditions on 27 July ranged from fog in the morning to partly cloudy and clearing in the afternoon. Time of collection for this mission was 1330 hours. Shadows over the minefield were minimal. Air temperature was 26°C. In short, weather conditions and sun angles appeared to be ideal.

2.2 PHOTOGRAPHIC COLLECTION

Three types of aircraft and camera systems were used in the collection of photographic data:

1. A U.S. Navy RF-8G with KS-87B framing camera;
2. A U.S. Army OV-1D Mohawk with KA-76 camera; and
3. A civilian light aircraft with a U.S. Army Minicam and operator.

The OV-1D and Minicam collection were made during the period of 18 through 20 July 1979. The weather conditions were ideal with maximum sunlight and little or no cloud cover. The OV-1D was scheduled primarily to provide infrared (IR) coverage of the array, with the aerial camera operational for test purposes only. The photo coverage, although acceptable, was not completely useful because no data clock or clock information was available. Altitude information was available on the IR imagery, but this could not be directly correlated with the photography.

The U.S. Army Minicam, a hand-held motorized Nikon with 180 mm lens, provided high resolution photography. The problem associated with this collection was that no data were recorded by the camera's operators as to altitude, standoff distance, and field angle. While the resultant imagery was acceptable, the lack of accompanying data distinctly limited its potential value for analysis.

The Navy RF-8G was scheduled for collection during the period 25 through 27 July. Inclement weather — rain and low cloud cover — ruled out coverage for 25 and 26 July. On the 27th, the scheduled morning, coverage was cancelled due to heavy fog over the minefield. All acceptable RF-8G photography was obtained during the afternoon when weather conditions were ideal.

Although only one-half day's data were collected, the Navy photography was selected for evaluation. There were several reasons for making this selection:

1. This collection offered a variety of vertical coverages at altitudes ranging from 1700 ft to 8500 ft.
2. Oblique coverage, in four look directions, was also available.
3. The film used in the collection, EKC3411, was of good quality.
4. The imagery provided good stereo coverage of the array. This made it possible to study obscuration and sensor access in detail.

2.3 CAMERA AND FILM CHARACTERISTICS

The RF-8G aircraft employs the RS-87B aerial camera, a 13 cm reconnaissance frame aerial camera. The 13 cm size corresponds to the 5 in. wide film used in the camera. The film is encased in a

cassette magazine containing 500 ft of film. The yield derived from a cassette of this size is 1200 frames. The KS-87B has focal plane shutter speeds ranging from 1/60 to 1/3000 sec. Exposure control may be automatic or exposure may be changed manually from within the cockpit. In vertical configuration, its angular coverage varies with the focal length. For this collection, a 6-in. focal length was used resulting in an angular coverage of 41°06'. The camera is also capable of being used in various oblique configurations by using depression angles of 5°, 15° and 30° from nadir.

The film used for this data collection was EKC 3411 (Kodak Plus-X Aerocon), a panchromatic negative film intended for medium-to-high altitude reconnaissance. The basic exposure is about 1/500 sec at f/8, for a solar altitude of 20°, an altitude of 10,000 ft, and a clear day. This film should have been processed in a Kodak VERSAMAT film processor; instead, it was processed in a government specification, general purpose film processor.

The film duplicate positive (DP) was processed on SO-192. At close inspection, one will discern what appears to be spotting on the DP. The original negative was imbedded with minute particles of dirt or dust. When the DP was processed, these dirt specks became readily apparent to the eye. The DP was considered acceptable for interpretation because the actual scene was not marred or distorted by this effect.

2.4 SCALE, ALTITUDE, AND GROUND COVERAGE DETERMINATION

The information furnished by the pilot on the Photo Data Card was incomplete. It was necessary, therefore, to derive the photo scale reciprocal (PSR) by measuring objects of a known size on the image. The scale derived by this method may be considered acceptable because the measured objects were on relatively flat terrain and their exact dimensions were known. Three objects were measured so that a usable scale check could be made. The objects measured were:

Object	Measurement
M60 Tank	Length - 22.83 ft
M113 APC	Length - 15.96 ft
Pool No. 2	12 ft square

The PSR was calculated by the following formula:

$$PSR = \frac{\text{Ground Distance (GD)}}{\text{Photo Distance (PD)}}$$

Once the approximate scale had been obtained, it was a relatively simple matter to establish the altitudes flown for each coverage. This was accomplished by:

$$H = f \times PSR$$

where H = flying height above ground, ft, and f = focal length (0.5 ft). Table 2-1 is a list of the various PSR's and altitudes used in this report. The data is presented by Event (frame) numbers. The aircraft flight directions for each image are also provided.

After altitude (H) has been established, the dimensions of the area photographed in each frame can be established. Since frame size is 4.5" x 4.5", the photographed area is square when taking photographs directly below the aircraft. Each side of the ground area exposed can be calculated from the expression

$$G = \frac{HP_s}{f}$$

where G = side length (ft)

P_s = frame size (inches)

f = focal length (inches)

H = aircraft altitude (ft)

The dimensions of the squares photographed for the various collection altitudes are given in Table 2-2.

TABLE 2-1
ALTITUDES AND PHOTO SCALE RECIPROCALS FOR
SELECTED EVENT (FRAME) NUMBERS

Event	Altitude (ft)	PSR	Flight Direction
4970	2100	1:4200	North
4981	1750	1:3500	East
4995	1770	1:3400	South
5012	1900	1:3800	West
5074	2200	1:4400	North
5080	1800	1:3600	East
5085	1800	1:3600	South
5088	1900	1:3800	West
5091	5500	1:11,000	North
5096	6000	1:12,000	East
5101	3500	1:17,000	South
5103	7500	1:15,000	West

TABLE 2-2
GROUND COVER FOR REPRESENTATIVE ALTITUDES

Event	Altitude (ft)	Side Length G (ft, m)
4995	1700	1275, 389
5012	1900	1425, 434
5074	2200	1650, 503
5096	6000	4500, 1372
5101	8500	6375, 1943

2.5 BASIC PHOTOINTERPRETATION APPROACH

A standard photo search procedure was used in the initial examination of the photography. First, the array was scanned in a monoscopic manner, that is, it was viewed without stereo vision. This allowed the interpreter to select areas for more detailed study later. Knowing the general layout of the array, the interpreter scanned the surface mine elements first, followed by the elements having handburied mines, the mine furrows (both covered and uncovered), the minecord, the dummy mine holes, and the artillery-scattered mines. Table 2-3 presents the results of the initial monoscopic scan.

Second, the array was searched by using the stereoscope. The array elements were stereo searched in the same sequence as the mono scan. The search yielded somewhat different results, but not significantly better that would indicate stereo search to be the preferred method. Stereo viewing, however, allowed the interpreter to examine, in detail, the effects of mine obscuration by the vegetation. Table 2-4 presents results for the stereo search.

Each element in the array, both mono scan and stereo scan search, was rated as being:

D - Detectable
PD - Partially Detectable
ND - Non Detectable

The "D" rating means that one is capable of detecting an element's total number of mines, or a major portion of them. The "PD" rating detects only a small portion of the mines in a specific element (less than 50 percent). The "ND" rating was assigned when the mines in any element were not detected. This was usually the case for the element containing the simulated PM-60's.

TABLE 2-3
MONO SCAN RESULTS

Event* No.	Altitude ft	Element #1	Element #2	Element #3	Element #5	Element #6	Element #7	Element #8	Element #9	Element #10	Element #11 & 15	Element #12 & 16
4970	2100	D	ND	D	D	D	D	D	D	D	PD	ND
4981	1750	PD	ND	D	D	D	D	D	D	D	PD	ND
4995	1700	D	PD	D	PD	PD	D	D	D	D	PD	ND
5012	1900	D	ND	D	PD	PD	D	D	D	D	PD	ND
5074	2200	D	ND	D	PD	PD	D	D	D	D	PD	ND
5080	1800	ND	ND	D	D	D	D	D	D	D	PD	ND
5085	1800	ND	ND	D	ND	D	D	D	D	D	PD	ND
5088	1900	D	PD	D	PD	D	D	D	D	D	PD	ND
5091	5500	ND	ND	D	ND	ND	D	D	D	ND	PD	ND
5096	6000	ND	ND	D	ND	ND	D	D	D	ND	ND	ND
5101	8500	ND	ND	PD	ND	ND	D	D	D	ND	ND	ND
5103	7500	ND	ND	D	ND	ND	D	D	PD	ND	ND	ND

* Event Corresponds to Frame Numbers

Legend: D = Detectable
PD = Partially Detectable
ND = Non-Detectable

TABLE 2-4
STEREO SEARCH RESULTS

Event* No.	Altitude ft.	Element #1	Element #2	Element #3	Element #5	Element #6	Element #7	Element #8	Element #9	Element #10	Element #11 & 15	Element #12 & 16
4970	2100	D	ND	D	D	D	D	D	D	D	PD	ND
4981	1750	D	ND	D	D	D	D	D	D	D	PD	ND
4995	1700	D	PD	D	D	D	D	D	D	D	PD	ND
5012	1900	D	ND	D	D	D	D	D	D	D	PD	ND
5074	2200	D	ND	D	D	D	D	D	D	D	PD	ND
5080	1800	D	ND	D	D	D	D	D	D	D	PD	ND
5085	1800	ND	ND	D	D	D	D	D	D	D	PD	ND
5088	1900	D	PD	D	PD	D	D	D	D	D	PD	ND
5091	5500	ND	ND	D	ND	ND	D	D	D	ND	PD	ND
5096	6000	ND	ND	D	ND	ND	D	D	D	ND	D	ND
5101	8500	ND	ND	D	ND	ND	D	D	D	ND	D	ND
5103	7500	ND	ND	D	ND	ND	D	D	D	ND	D	ND

* Event Corresponds to Frame Number

Legend: D - Detectable
PD - Partially Detectable
ND - Non-Detectable

2.5 OBSCURATION, GROUND RESOLUTION, AND CONTRAST

Several factors affected the detection of mines during this photo analysis. The first was obscuration of the mine or mines by the vegetation. The second dealt with the effects of ground resolution. The third factor involved contrast of the images. Obscuration, limited resolution, and poor contrast combined to heighten the difficulty for detecting mines, especially such types as the PM-60's.

Obscuration of the mine is caused when vegetation is interposed between the mine and sensor. This causes the camera access to the mine to be interrupted or disturbed, and results in the target mine not being imaged (Figure 2-3).

The analysis of camera system resolution is described by Y. Morita in ERIM Report 138300-59-T (July 1980) titled "Effects of Resolution Field of View and Vegetation on Sensor Access." The analysis was done to study the effects of system resolution, obscuration, and platform characteristics on search rates and response times. The analysis was originally adopted for the KA-30 camera; however, the KS-87B has the same film format and angular coverage. His analysis is as follows:

"Resolution capabilities of cameras are stated in terms of line pairs/mm. If the FOV and the frame size are given, the resolution can be stated in terms of milliradians and the above analytical approach can be applied. As an example, consider the KA-30A framing camera. Its frame size is 4.5" by 4.5" and its field of view is 41° 06' (717.3 mrad) per side. The side length times the resolution in line pairs/mm divided by the field of view in milliradians yields line pairs per mrad, that is, 114.30 mm (40 line pairs/mm)/717.3 mrad = 6.37 line pairs/mrad. In Section 3, the relationship between mine diameter, resolution capability and altitude was derived. This relationship is

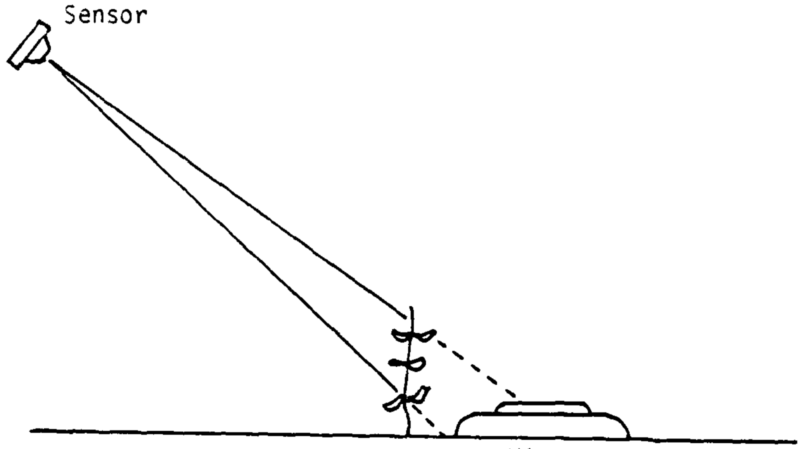


Figure 2-3. Obscuration by Vegetation

$$h_a = \frac{d \cos^2 \phi}{n\Delta\phi}$$

For cameras, ϕ represents half the field of view (Figures 2-4 and 2-5). But $n\Delta\phi$ is the angle subtended on the mine. If n is 1 line pair and there are 6.37 line pairs/mrad, the subtended angle $n\Delta\phi$ is 1/6.37 or 0.157 mrad. At $\phi = 41.1^\circ/2$, the altitude is calculated to be 1675.4 m for a 0.3 m diameter mine. The number of line pairs at the center of the frame will be 1.14. The size of the area imaged is approximately a 1300 m square at this altitude."

The relationship between the vegetation's obscuration and a mine is based on the requirement that the interpreter must see a portion of the mine to be able to detect it. The detection of mines under this condition is expressed by:

$$X_m = \frac{Hkd}{h_v}$$

where X_m = half of effective swath width for mine detection

k = maximum allowable fraction of vegetational observation over mine

d = diameter of the mine

H = height of camera above terrain

h_v = height of vegetation.

An alternate limit on the effective swath width for mine detection is the angular field of view of the camera. If this factor limits the effective half swath width,

$$X_m = H \tan \phi_{sv}$$

where ϕ_{sv} is the side view scan angle.

If the effective swath width is limited by vegetation height, the portion or fraction of the entire area covered by the field of view of the camera which is observable is approximately

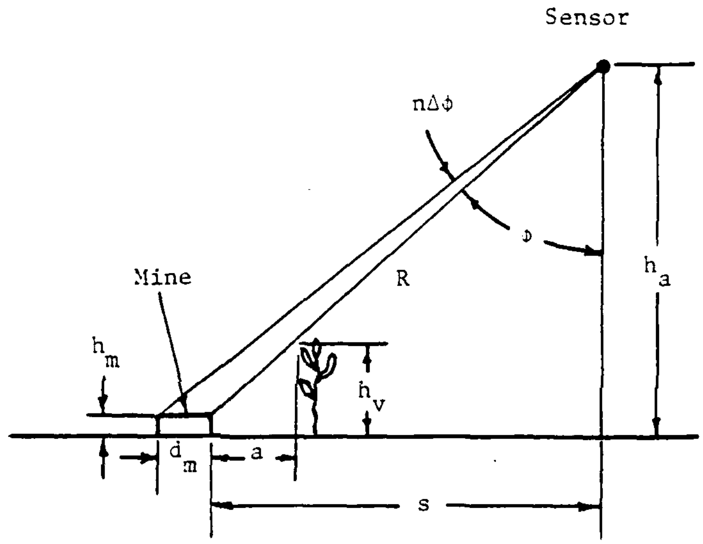


Figure 2-4. Sensor, Mine and Vegetation Geometry

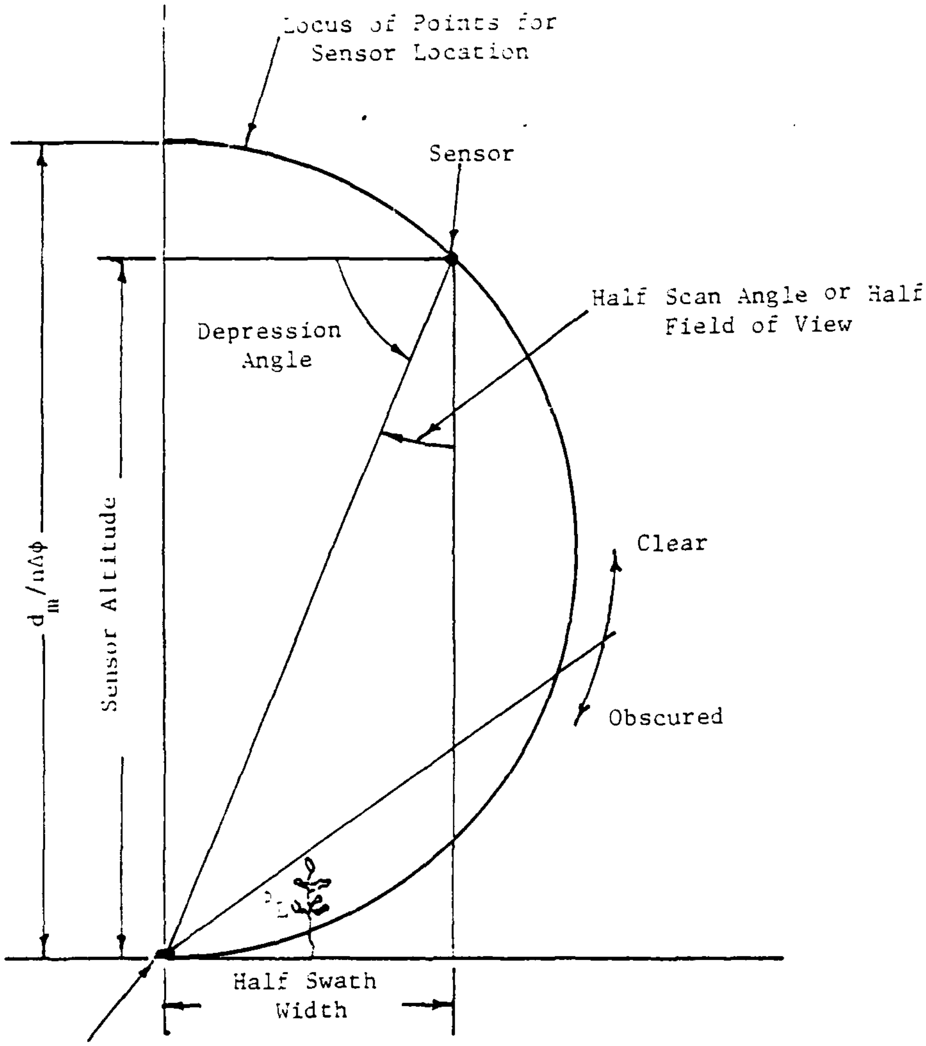


Figure 2-5. Geometric Definitions and Conditions

$$p = \frac{X_m}{H \tan \phi_{sv}} = \frac{kd}{h_v \tan \phi_{sv}}$$

where $0 \leq k \leq 1$. This fractional value is approximate because linear relationships are used; a mine must be square and properly oriented for the equation to be exact. Thus, the effective swath width

$$X_m = \text{Smaller of } \frac{Hkd}{h_v} \text{ or } H \tan \phi_{sv}$$

Figure 2-6 is a plot of half the effective swath width for vertical photography, assuming the use of the KS-87B camera. The KS-87B has an angular coverage of 41°06'. Thus, ϕ_{sv} is equal to 20°33' (Figure 2-7). For the calculations, the mine diameter, d, equals 0.9 ft and the shadow length, kd, equals 0.45 ft (k = 0.5). The altitudes given are representative of those flown during the collection. The effective swath widths for vegetation heights of 0.5 and 1 ft are equal to each other, because the ϕ_{sv} limit is in effect until h_v equals 1.20 ft.

In Array I, the height of the alfalfa was approximately 1.5 ft at the time photographs were taken.

The second factor having an effect on this analysis was ground resolution. This term describes the ability to resolve ground features on a photograph. Another term "minimum ground separation," comes into context for this discussion. This is the minimum distance between objects on the ground at which they can be resolved on the photograph (Figure 2-8). Ground resolution, while clearly related to scale, is a measure of the interpretability of an aerial photograph. The photointerpreter requires a ground resolution sufficient to identify the smallest object of interest. The better the ground resolution, the better the image quality; and consequently, the better the information content.

The third factor examined in this analysis was image contrast. This is interpreted as being the difference in brightness between

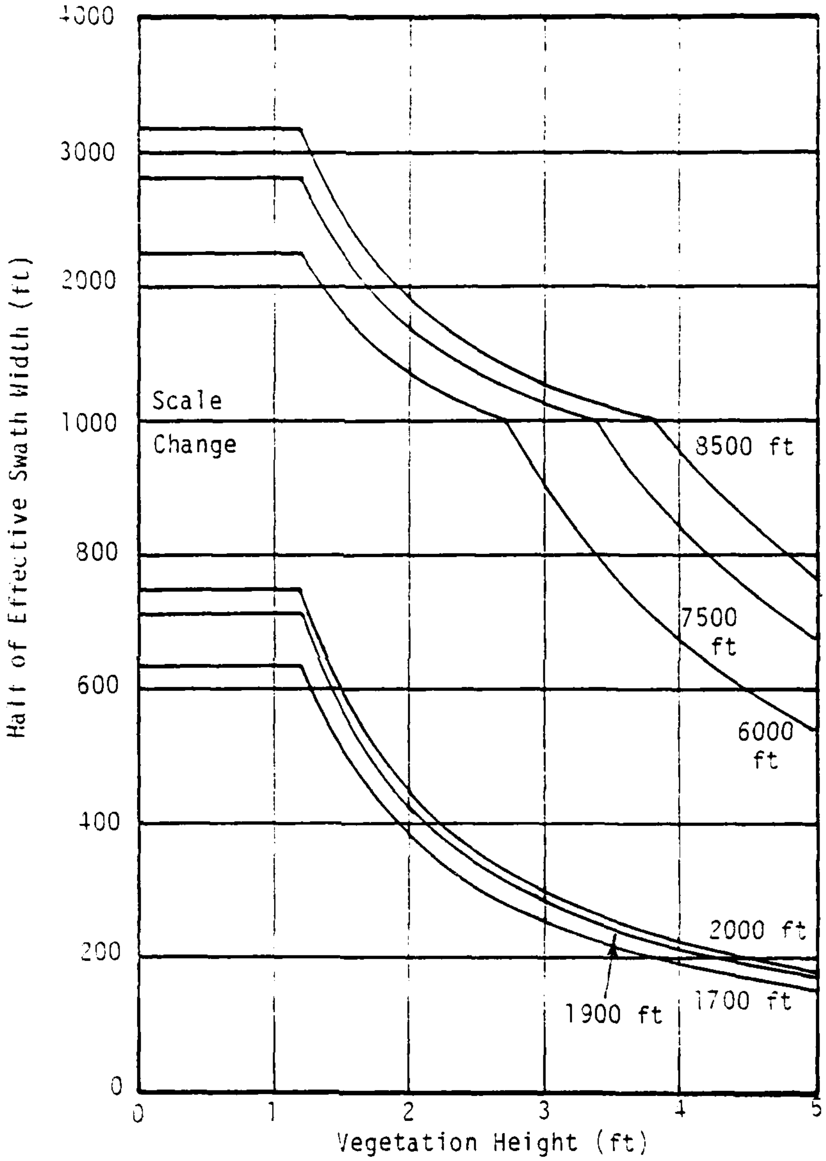


Figure 2-6. Swath Width As Function of Aircraft Altitude and Vegetation Height

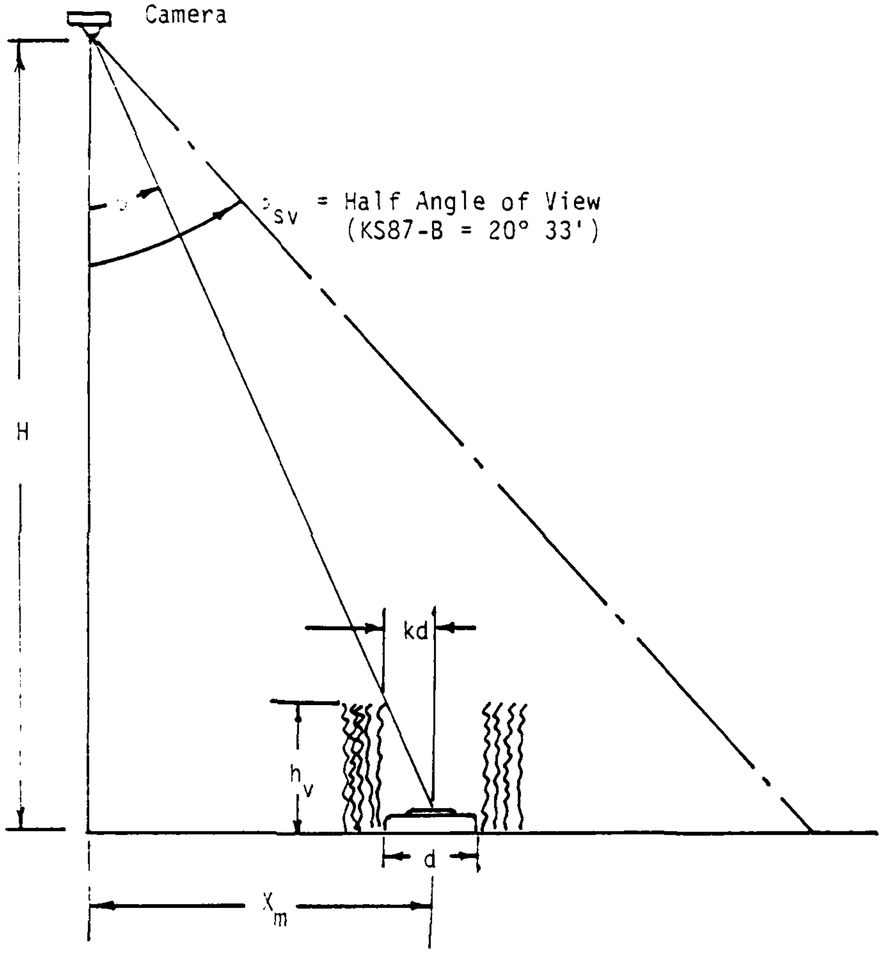


Figure 2-7. Vegetational Obscuration of the Mine

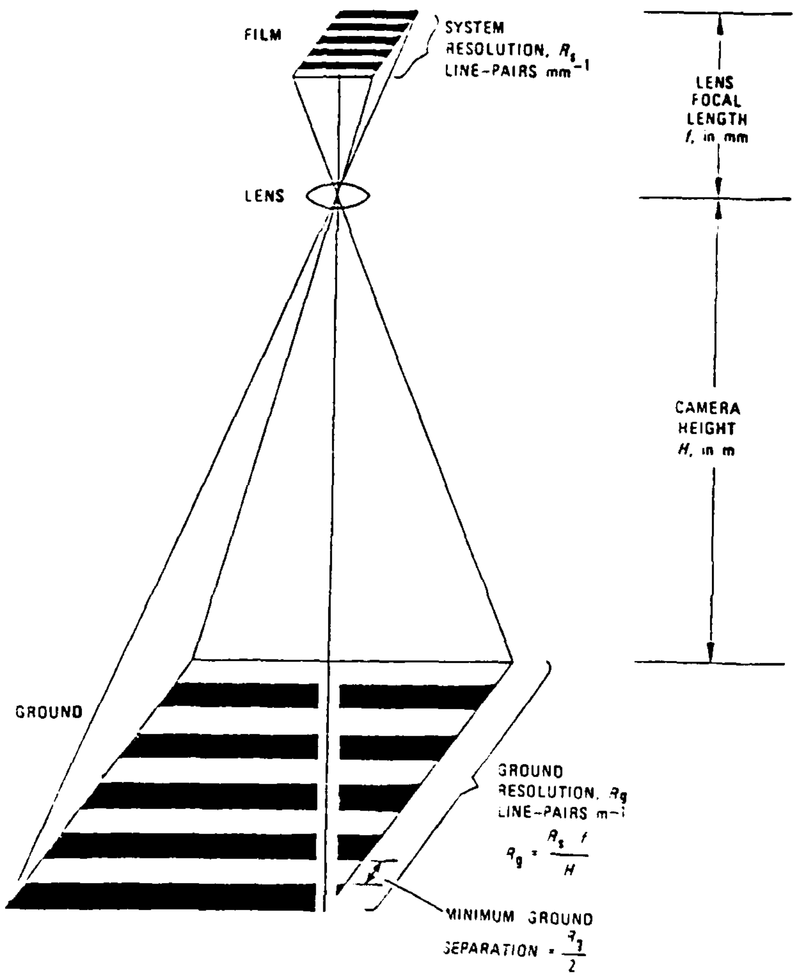


Figure 2-8. Ground Resolution and Minimum Ground Separation on Aerial Photographs

objects in the image. Contrast also refers to the differences in target luminance. In this analysis, the coloration of the background (the alfalfa field) appeared to merge with that of the mines, especially the PM-60's and the TM-46's. The M-19's, which reflected considerable light back to the camera, were readily detectable. There was no method readily available to measure the contrast ratio (C_r) for the photography used in this analysis. One may assume a low contrast ratio given the near uniform shade of the nondetectable mines and the uniform brightness of the target background. The low contrast ratio definitely had an effect on the interpreter's ability to resolve and detect mines.

2.7 THE DETECTION PROBLEM

The detection of the surface-laid PM-60's and TM-46's proved to be a difficult task. The other portions of the array were considerably easier to detect. The detection problem was caused by the factors cited previously — obscuration by the vegetation, ground resolution, and contrast. The search techniques of mono scan and stereo search were helpful; however, this approach was contaminated because the interpreter was familiar with the ground truth concerning the array. These techniques might not have been as helpful if the interpreters were not familiar with the area or the mines.

The spatial extent of an object such as the PM-60 or TM-46 is very small. These mines have a round, uniform shape with no aspect ratio. A search of the photography would require the interpreter to look not for a single mine, but rather, for a considerable number of them in a discernible pattern. The surface mines located in the alfalfa (1.5 ft high) were not detected in the mono scan. Only a small portion (less than five) were detected during the stereo search. This occurred in a part that was sparsely vegetated (Figure 2-9). There was little or no difficulty in the areas of the array that contained the hand buried mines and the mine furrows.

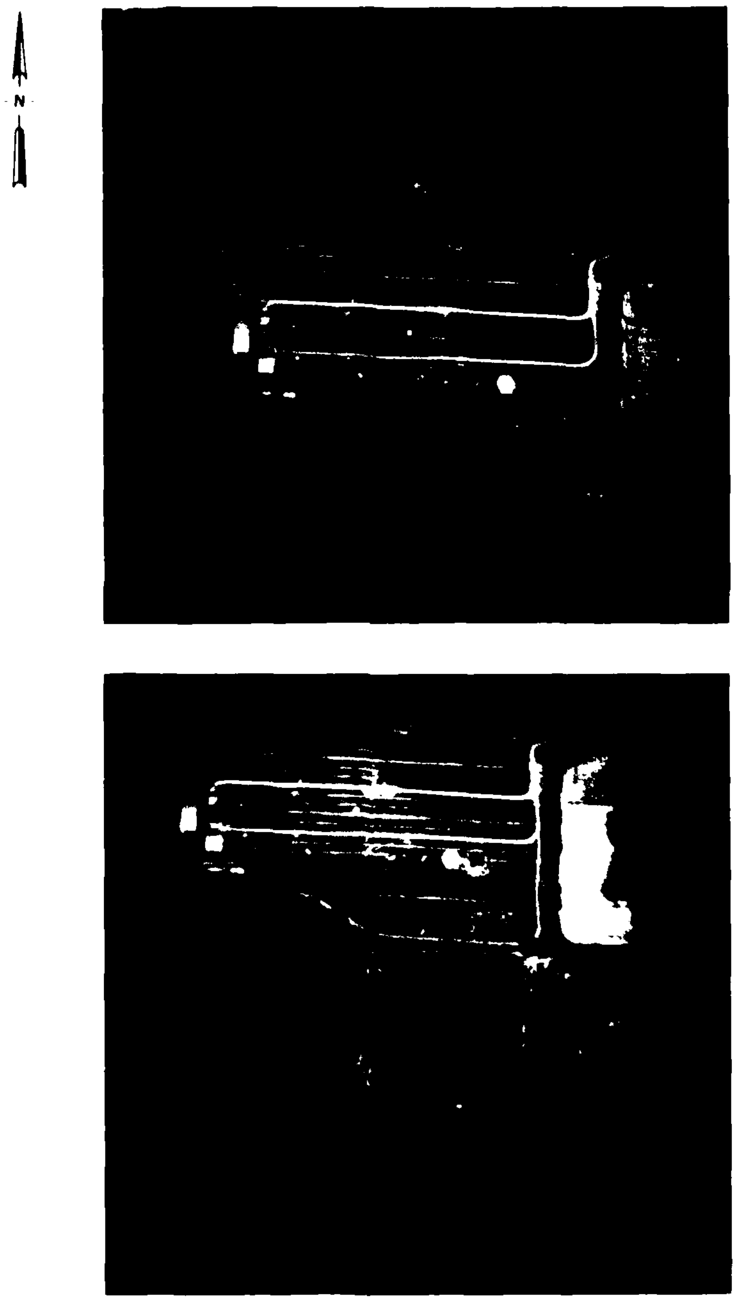


Figure 2-9. Stereo Pair of Array I

Their detection may be attributed to the surface disturbance caused by their burial and by the readily recognizable signature left by the mine layer. The artillery scattered mines were not detected in either mono scan or stereo search. Their extremely small size could not be sufficiently resolved on the photography.

In addition to the size (ground distance) of the PM-60, TM-46, and the artillery scattered mines, other considerations should be noted:

1. The brightness of the mine to be resolved;
2. The uniformity of the target background; and
3. The extent of the uniform background against which the mines were imaged.

For example, the PM-60's were painted with the TTE 529 olive paint which closely simulated the paint found on the actual model. When photographed, this color blended perfectly with the surrounding vegetation. A similar effect occurred in the case of the TM-46, although not to the same degree. The artillery scattered mine, also painted an olive drab color, reacted in the same manner. The PM-60, TM-46, and artillery scattered mines exhibited monotonous, nearly uniform shades of gray on the film. The M-19 mines, on the other hand, appeared as distinctively bright objects when photographed against the darker background. This may have caused them to appear larger than their actual size. Contrast ratio was a crucial issue in detecting the two most critical types of mines, the PM-60 and TM-46.

3
CONCLUSIONS AND RECOMMENDATIONS

Although the amount of photography available was limited, some conclusions may be made from this analysis:

1. Standard search procedures, both mono scan and stereo search, must be refined to a greater degree for mine detection. This may require an examination of the utility of collateral materials to augment the information content of the photography.

2. Obscuration by vegetation had an impact, as expected, but it was not a major negating factor. It did contribute to the problems caused by ground resolution and contrast.

3. Ground resolution had a severe impact. This is due simply to the size of the mines themselves. Ground resolution may be improved through proper selection of flight altitudes and focal lengths.

4. The contrast ratio for this film, EKC 3411, was low. Given the coloration of the crucial mines (PM-60 and TM-46) and the uniformity of the background, their detection proved to be an arduous task.

Additional, more complete analyses of aerial photographic methods are required. Furthermore, certain recommendations were derived from this analysis.

1. An investigation for new search techniques should be conducted. This may be accomplished by reviewing the pertinent literature, and by consultations with the photographic intelligence community.

2. A data base that documents different types of vegetation and their seasonal heights should be developed. This would, in turn, serve as a tool for developing sensor access tables that the user may employ in

selecting the optimum sensor, altitude, and field of view for mine detection.

3. Films that render a higher ground resolution than that encountered heretofore should be tested and analyzed for their utility in mine detection. Every film should be evaluated for its capability in resolving very small target objects.

4. Films and developers that yield medium to high contrast imagery should be investigated. EKC 3411, while acceptable, did have a low contrast ratio in this collection. Perhaps it may prove to be a different matter under different target conditions.

Finally, it must be stressed that this experiment was conducted to generate qualitative data to provide insight into the potential of photography for minefield detection. It has led to the general conclusions that resolution and sensory access play major roles in determining usefulness of photography in a minefield detection role.

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